An MTConnect Ontology for Semantic Industrial Machine Sensor Analytics

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Abstract. The vision of moving towards more autonomous systems in the industrial domain requires the efficient use of information. The frequent absence of well described assets and the poorly structured and non-available live data is considered as one of the main roadblocks towards this future. This paper addresses these issues by creating an ontology for the MTConnect standard. MTConnect provides the basis to describe machines, their device structure including sensors and their measurement values. The ontology is tested using live data and we further provided multiple queries to execute certain machine health tests.

Keywords: Industry 4.0, MTConnect standard, Industrial Control Systems, Ontology, Semantic technologies

1 Introduction

The Industry 4.0 vision [5] of smart manufacturing [6] and cyber-physical systems [8] requires an efficient and effective exchange of information. In the context of shop floor equipment and software applications, MTConnect [13][3] is a recently proposed standard to provide the basis for data exchange between different shop floor equipment and software applications. MTConnect defines specific data patterns to facilitate healthcare monitoring of machine tools. Thus, it provides the basis for predictive maintenance to reduce the possibly premature exchange of expensive machine parts or to prevent entire machine outages due to broken parts based on sensor data.

The MTConnect standard is published as a document[4] (PDF) and consists of an implementation in a machine-readable format (XML). This paper proposes the implementation of MTConnect as machine-interpretable ontology (OWL) to achieve two things: First, to preserve the semantics of the reference within the model and second, to enable its interlinking with other datasets to form the basis of the Industry 4.0 vision. Semantic-based approaches facilitate information flows in contrast to established closed data silo environments as well as vendor-logged in ERP systems. Furthermore, we defined multiple machine healthcare

[3] http://www.mtconnect.org/
[4] http://www.mtconnect.org/standard-documents

evaluation queries (SPARQL) to lay the groundwork for standardized machine evaluation methods.

The ontology tested using a qualitative evaluation by checking its semantic correctness, by creating sample data and by running multiple sample queries.

After all, the ontology contains 80 classes, 12 object properties and 43 datatype properties. We further developed 12 SPARQL queries for checking the machine health and for retrieving structural information.

2 Related Work

The related work section is organized as follows: We first review existing industrial ontologies and relevant standards, then we provide an overview on existing sensor standards and finally list important device-based ontologies.

While the European industry standardized the Open Platform Communications Uniformed Architecture (OPC UA) standard [5] [9], the US industry defined the MTConnect standard.

Several ontologies have been created in the manufacturing and engineering domain. Specifically, in [4] an ontology is being developed for modeling assembly systems, their parts, their behavior and information. A use case of how industrial standards can be transformed into ontologies for cutting and turning tools is proposed in [3]. Industrial robots used in manufacturing kitting stations are modelled in ontologies presented in [7] in a project from the National Institute of Standards and Technology (NIST)[6]. SCORVoc [11] is a developed vocabulary which formalizes the SCOR standard in the supply chain domain.

A considerable number of ontologies have been also developed focusing on the modelling of sensors and their measurements. SSN[7] (Semantic Sensor Network) ontology [1] is the most popular and adopted sensor ontology which describes sensors and the data obtained from them. SSN is based on global geospatial (sensor) standards developed by OGC (Open Geospatial Consortium)[8].

Ontologies are further used for representing the structure of devices and the different components that they consist of. As part of the Smart Appliances Project[9], the Saref ontology [2] provides a common standard for representing smart devices and their functions. Combining both sensors and device concepts, Staroch [14] has developed an ontology based on weather data collected from sensors in order to be used by smart home devices.

Taking into consideration all the described approaches, the MTConnect ontology is the first attempt to model industrial machines and their data based on the MTConnect standard.

[5] https://opcfoundation.org/
[6] https://www.nist.gov/
[7] https://www.w3.org/TR/vocab-ssn/
[8] http://www.opengeospatial.org/
[9] https://sites.google.com/site/smartappliancesproject/home

3 Implementation

The MTConnect ontology is developed manually based on the provided documentation of the MTConnect standard as well as existing data published conforming to MTConnect. The ontology file (RDF) is expressed in the Turtle (Terse RDF Triple Language) [12] format for the sake of its simplicity and the easy of readability for the human eye.

3.1 Methodology

The building of our ontology follows the top-down approach [10] as well as the one proposed by Uschold et al. [15], which contains the following steps:

- **Scope.** The developed ontology fully conforms to the MTConnect standard (Version 1.3.1). No further concepts are added or missing, which are not part of the standard.
- **Capture of the Ontology.** The MTConnect official specification[10] [13] and the acquired XML data[11] are the sources on which the developed ontology is based.
- **Reuse of Existing Ontologies.** Concepts and properties from the Semantic Sensor Network Ontology (*ssn*)[12], the Smart Appliances REFerence (*saref*) ontology [13], the Simple Event Model Ontology (*sem*)[14] as well as the recommended best practises on *Simple part-whole relations*[15].
- **Ontology Documentation** The ontology is available on GitHub[16] together with a human-readable presentation (HTML) of the ontology.

3.2 Ontology Development

```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix owl:  <http://www.w3.org/2002/07/owl#> .
@prefix rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xsd:  <http://www.w3.org/2001/XMLSchema#> .
@prefix mto:  <https://raw.githubusercontent.com/vocol/MTConnect/master/
    MTConnect.ttl> .
mto:Component
                rdf:type owl:Class;
                rdfs:label "Component"^^xsd:string;
                rdfs:comment "Defines the structure of the physical or
                logical parts of a device that provide more precise
                definition for the structure of the device."@en.
```

Listing 1.1. Class definition in Turtle

[10] http://www.mtconnect.org/standard-documents/
[11] https://smstestbed.nist.gov/vds/
[12] https://www.w3.org/2005/Incubator/ssn/ssnx/ssn
[13] https://w3id.org/saref#
[14] http://semanticweb.cs.vu.nl/2009/11/sem/
[15] https://www.w3.org/2001/sw/BestPractices/OEP/SimplePartWhole/
[16] https://github.com/vocol/MTConnect

We started the development of the ontology by first defining the perceived core concept of the standard: *Device*. A device is defined as a single piece of equipment e.g. a machine or any set of elements that operate together to perform a function. The different parts that form a device are described by using the concept *Component* (Listing 1.1) which contained the subclasses *Axe*, *Sensor*, *Controller*, *System*, *Actuator*, *Stock*, *Interface* and *Door*. Furthermore, each of those subclasses contain more subclasses. For example, the class *Axe* consists of the subclasses *LinearAxe* and *RotaryAxe*, which are types of axes. The class *Path* is the subclass of the *Controller*. This hierarchical structure is preserved in our ontology.

The measurement values of the sensors are defined by MTConnect using so called *data items*. Therefore, we defined the class *Dataitem* which contains subclasses such as *Temperature*, *Availability*, *Condition*, *Angle* and *Pressure* to represent these numeric or non-numeric values that are related to the machine status. The object property *ssn:hasPart* is use connect the different device parts and *ssn:hasSubSystem* to define the respective sub components. The datatype property *saref:has_Name* is used to define the device name.

The datatype property *sem:hasTimeStamp* defines the exact date and time that an event occurred and the *part:partOf* describes the relationship between different parts of a device.

Figure 1 provides an overview of the MTConnect ontology main concepts.

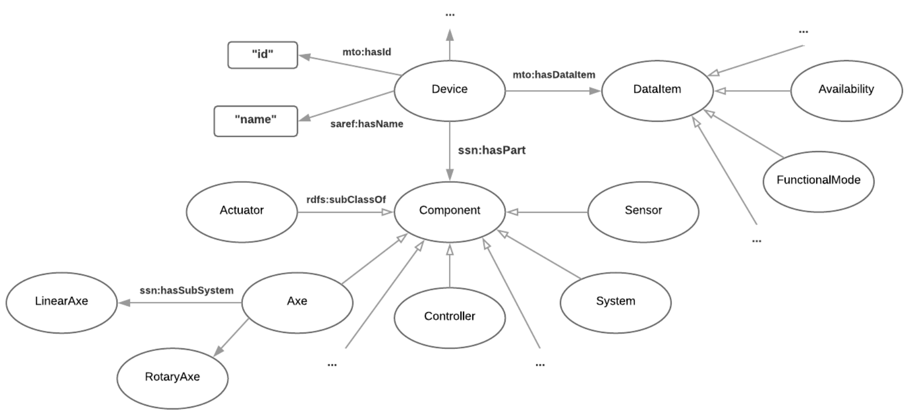

Fig. 1. Machine structure introduced by MTConnect

4 Evaluation

We evaluated the ontology using a qualitative evaluation. We tested the semantic correctness of the ontology, we created sample instances based on live data to ensure its completeness and finally, we developed and tested multiple SPARQL queries to provide proof that the ontology is able to return the expected results in certain machine health and structural queries. While executing the queries, no performance issues were observed.

4.1 Semantic validation

We used the *OOPS!* (OntOlogy Pitfall Scanner!)[17] for inspecting gaps in the context of the created ontology. As a result, no errors or warning were raised in this test.

4.2 Sample Instances

We further created sample instances based on live stream data published by National Institute of Standards and Technology (NIST)[18] to the validate the completeness of our ontology. The format of the live stream data is XML and available via the Smart Manufacturing Systems endpoint[19]). Due to the poor experience with automated methods, we decided to create a few the sample instances manually.

```
mto:Agie01
        a ssn:Device, owl:NamedIndividual;
        rdfs:label "Agie01";
        saref:hasName "GFAgie01";
        saref:hasDescription  "Agie Mikron HPM600U - GF Agie Charmilles
            HPM600U";
        saref:hasManufacturer "Agie Charmilles";
        saref:hasModel "HPM600U";
        mto:hasCreationtime "2018-02-15T13:05:28Z"^^xsd:dateTime;
        mto:hasUuid "mtc_adapter001";
        rdfs:isDefinedBy mto: .
```

Listing 1.2. Device individual definition in Turtle

As a result, six samples corresponding to different machines are created based on our developed MTConnect ontology. Listing 1.2 depicts an example class instance expressed in Turtle.

4.3 SPARQL queries

In order to check the health status of the machines and their responses, we examined the condition values that are introduced by the MTConnect documentation. The provided minimum and maximum danger values indicate the operational status of the machines and notify for possible abnormal machine behaviors. Listing 1.3 displays a query to retrieve all the devices which have a *WARNING* condition and returns the condition message.

[17] http://oops.linkeddata.es/
[18] https://www.nist.gov/
[19] https://smstestbed.nist.gov/vds/

```
SELECT ?device ?message
WHERE {  ?device     ssn:hasPart              ?component.
         ?component  mto:hasDataItem          ?dataitem.
         ?dataitem   mto:hasCondition         "WARNING";
                     sem:hasTimeStamp         ?timestamp;
                     mto:hasConditionMessage ?message. }
```

Listing 1.3. SPARQL condition query

With the use of SPARQL queries it is also possible to observe the structural design of a machine. For example, Listing 1.4 shows all the components and subcomponents that are part of a device.

```
SELECT *
WHERE { ?device    ssn:hasPart      ?component.
        ?component ssn:hasSubSystem ?subcomponent.}
ORDER BY ASC(?device)
```

Listing 1.4. SPARQL structural query

We created in total 12 SPARQL queries related to the MTConnect ontology which are all available on the GitHub repository. All queries are executed in the GraphDB[20] environment and were executed within 0.5 seconds such that no performance issues were observed.

5 Conclusions & Future Work

This paper introduces the MTConnect ontology, which is based on the MTConnect manufacturing standard, along with standardized SPARQL queries which can be reused from companies and facilitate the control and management of their manufacturing machines.

Overall, the combination of semantic web technologies and industrial standards can enhance interoperability between companies by adding semantic value to the data representation. We plan to engage with the MTConnect standardization community to move this goal forward.

To compare in the future developed MTConnect-compliant systems, we consider the provision of MTConnect benchmark datasets an important next target. We plan to do a quantitative evaluation in the near future to test the performance of our ontology.

An observation: By adding maximum and minimum values for certain danger values (e.g. Temperature) in the standard, one could develop more expressive SPARQL queries to build more autonomous systems. However, we assume that the reason for the lack of those values might be that it depends on the vendor of the device.

Finally, as part of future work, we suggest that the MTConnect ontology could be combined with machine learning algorithms in order to support predictive maintenance techniques in the manufacturing sector.

[20] https://ontotext.com/products/graphdb/

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